SENNA – Device for Explosives' Detection Based on Nanosecond Neutron Analysis

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ABSTRACT

Portable device for explosives' detection (SENNA) based on Nanosecond Neutron Analysis and Associated Particles Technique (NNA/APT) has been built and tested. SENNA is a single suitcase weighting 35 kg; it is remotely controlled from any PC-compatible computer. Inside is an APT neutron generator with a 3×3 matrix of semiconductor detectors of associated α-particles, two BGO-based detectors of γ-rays, fully digital data acquisition electronics, data analysis and decision-making software, and batteries. Detection is based on determining chemical composition of the concealed substance by analysing secondary γ-rays from interaction of "tagged" fast neutrons with its material. A combination of position-sensitive α-detector and time-of-flight analysis allows one to determine the location of the detected material within the inspected volume, and its approximate mass. Fully digital data acquisition electronics is capable of performing alpha-gamma coincidence analysis at very high counting rates, which leads to reduction of the detection time down to dozens of seconds. SENNA's scenario-driven automatic decision-making algorithm based of "fuzzy logic" allows one to detect not only standard military or industrial explosives, but also improvised explosives (including those containing no nitrogen), even if their chemical composition differs from that of standard explosives. SENNA can also be "trained" to detect other hazardous materials, such as toxic chemicals, if their chemical composition is in any way different from that of the surrounding materials.

Keywords: *explosives, detection, non-intrusive, neutrons, toxic chemicals*

Gorshkov, I.; Evsenin, A.; Vakhtin, D.; Kuznetsov, A.; Osetrov, O. (2007) SENNA – Device for Explosives' Detection Based on Nanosecond Neutron Analysis. In *Prediction and Detection of Improvised Explosive Devices (IED)* (pp. 17-1 – 17-18). Meeting Proceedings RTO-MP-SET-117, Paper 17. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int.

1.0 INTRODUCTION

1.1 Nanosecond Neutron Analysis

Nanosecond Neutron Analysis (NNA) [1, 2] is a further development of "neutron in, gamma out" method of non-destructive analysis of chemical composition of objects [3,4]. The method is based on detection of prompt γ-quanta from reactions of fast neutrons with the material of the inspected object in coincidence with the particles, which accompany emission of neutrons from the source. This allows one to significantly (by several orders of magnitude) reduce the background component in γ-ray spectra, and thus to reduce the time needed to detect concealed substances.

The time between emission of the neutron from the source and arrival of the secondary γ-quantum, which is produced by this neutron, to the detector is determined by:

- the time-of-flight of the neutron from the source to the point of interaction with the substance;
- a small addition due to time-of-flight of the prompt γ-quantum (which travels at a speed of light) from the point of interaction to the detector.

The first (dominant) component of the time depends on the distance to the inspected object and the velocity spectrum of the primary neutrons. For fast neutrons this time is typically in the range from several nanoseconds (neutron flight path tens of centimetres) to tens of nanosecond (neutron flight path several meters). All the γ-quanta, that are born in reactions of inelastic scattering of fast neutrons on nuclei of the material located in the inspected volume, must arrive to the detector within a narrow (few nanoseconds wide) time window. Gamma-quanta from other sources (cosmic background, natural radioactivity etc.) are not correlated in time with any of the neutrons emitted from the source, and such background events are suppressed.

If one uses a neutron source based on a DT neutron generator with built in position-sensitive detector of the associated α-particles, it is possible to obtain a separate energy spectrum of secondary γ-rays for each location inside the inspected volume ("voxel"), and thus to build a 3D image of the chemical composition of the material inside the inspected volume.

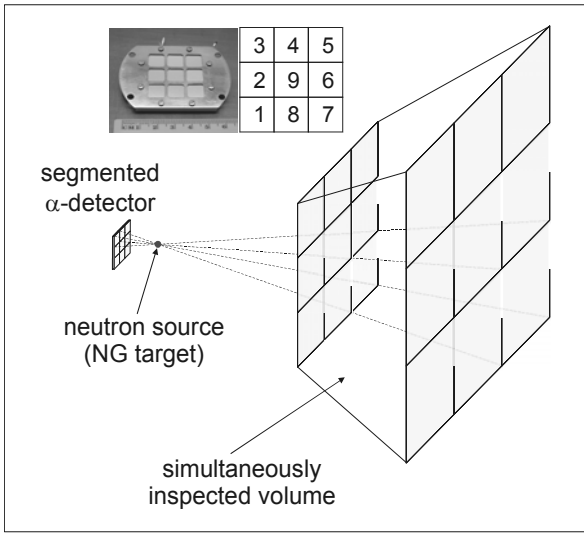

Figure 1. Principle of obtaining position information (3D image) in NNA.

Figure 1 demonstrates the principle of obtaining position information in the NNA. Use of a segmented or position-sensitive detector of associated α-particles allows one to divide the inspected volume into pixels in the plane of the α-detector, while analysis of the time of arrival of secondary γ-quanta relative to the α-particle provides information about the depth, at which the γ-quantum was born. A more detailed description of NNA can be found in [1, 2].

1.2 Main components of NNA-based devices

Any successful device for non-destructive inspection by NNA must fulfil certain requirement, that are shown at Figure 2. In case of a portable or a mobile installation, small weight, dimensions and power consumption must be added.

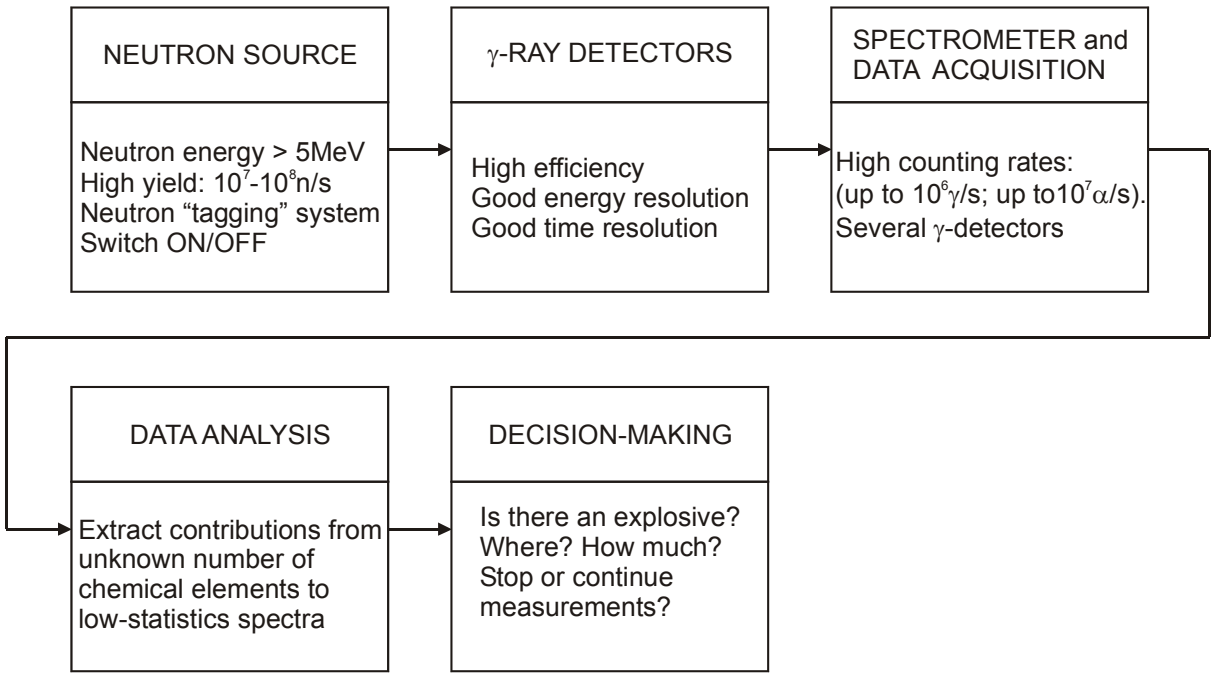

Figure 2. Components of an NNA-based device for non-destructive inspection.

At present the best sources of neutrons for NNA are portable DT neutron generators with built in position-sensitive detector of the associated α-particles. These generators are at present available from several companies. They are capable of producing up to 10^8 n/s, have small dimensions, weight and power consumption. Neutrons born in the generator in the reaction d+t→n+α have energy about 14 MeV and velocity about 5 cm/ns, and the α-particles born in the same reaction is emitted at ~180° to the direction of the neutron. If one installs a position-sensitive detector of α-particles close to the target of the neutron generator, he will be able to determine both the moment of emission of each neutron and its direction ("tagging" neutrons). Another advantage of neutron generators is that they can be switched off, and then safely transported and stored without a need in any radiation protection.

The detectors of γ-rays working in an NNA-based detection system, should have high detection efficiency for γ-quanta with energies in the range 0.5-8.0 MeV, and possess good energy and time resolution. Energy resolution of the γ-ray detector is directly related to the effect/background ratio, and thus to the time needed to determine chemical compound of the inspected substance. Time resolution determines in-depth position resolution of the system: for example, with 1 ns time resolution it is possible to determine the depth, at which the neutron has interacted with the matter with accuracy ~5 cm.

The spectrometer and data acquisition system (DAQ) of the NNA-based device must measure and store the following information: energy of each detected γ-quantum (E_γ); its time of arrival relative to the moment of detection of the α-particle, which accompanied the corresponding neutron (T_γ); flight direction of this neutron – by detecting the hit position of the α-particle detector (N_α). Unlike many other systems that are used for correlation measurements, this DAQ must be able to handle very high counting rates in both α-particle and γ-ray detection channels. For example, at the intensity of the neutron generator 10^8 n/s and solid angle to the detector of α-particles about 1 sr, the counting rate of the α-detector will be close to 10^7 s^{-1}. Typical counting rate of each γ-ray detector in such system will be well over 10^5 s-1, and one must envision the possibility of using a large number of γ-ray detectors.

The task of the data analysis in the NNA device is to determine contributions from different chemical elements (isotopes) to the measured energy spectra of γ-rays. The complexity of this task is connected with the fact, that in most but the simplest cases chemical composition of the inspected object is completely unknown, and it is necessary to consider a large number (typically twenty or more) different chemical elements. This makes conventional mathematical regression procedures (such as Least Squares Fit – LSF) almost useless, especially when one has to work with small statistics in spectra in order to reduce the measurement time in time-critical applications.

At last, work of the NNA device is not yet completed when relative concentrations of chemical elements in the inspected volume are determined. The operator is ultimately interested in whether the substance of interest (e.g. an explosive) has been detected, which type, where exactly, and how much. The decision-making procedure must answer these questions, using results of the data analysis procedure, as well as any other (not necessarily quantitative) available information about the operating conditions of the device and the measurement scenario. Besides, operator usually has no idea how long the measurements should last, since it depends on the unknown amount of concealed substance. Thus, the decision-making procedure must automatically determine the necessary measurement time from analysis of the experimental results.

2.0 PORTABLE DEVICE FOR EXPLOSIVES' DETECTION – SENNA

SENNA is a single suitcase containing the following components (see Figure 3):

- neutron generator with built in nine-segment detector of associated α-particles;
- two detectors of γ-rays with shielding;
- spectrometer and DAQ;
- computer with data analysis and decision-making software;
- power supplies and a battery.

The device is controlled from a remote computer via TCP/IP protocol using cable or a wireless connection. The total weight of SENNA is about 35 kg.

Figure 3. Device for detection of explosives SENNA.

2.1 Neutron generator with built-in detector of accompanying alpha-particles

SENNA uses a portable neutron generator NG-27 produced by VNIIA, Moscow, Russia, with built in nine-segment semiconductor detector of associated α-particles produced by APSTEC, St.Petersburg, Russia [2]. The used version of the neutron generator produces up to 5×10^7 14 MeV neutrons per second.

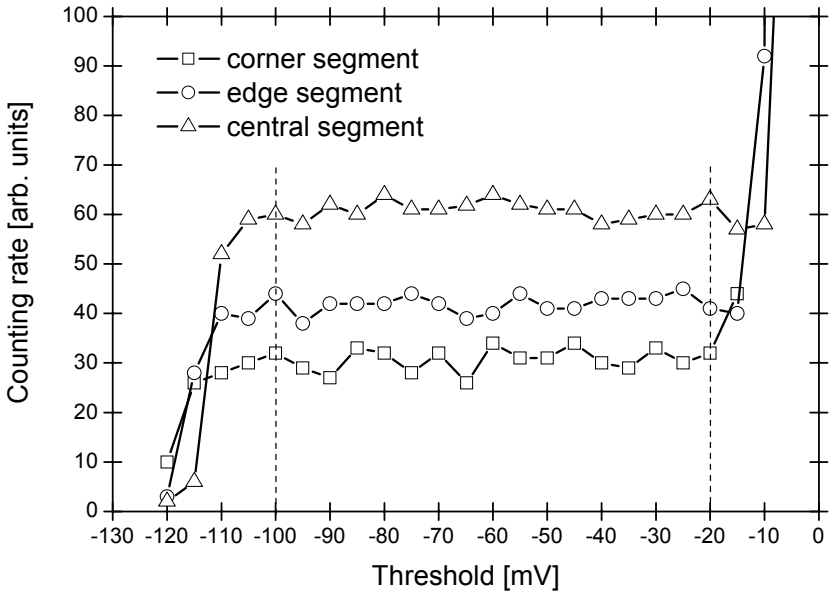

Figure 4. Dependence of the counting rate of ~2 MeV α-particles on the detection threshold for three segments of the α-particle detector.

The detector of α-particles built into the neutron generator is a matrix of nine (3×3) silicon detectors ("pixels") with area 1 cm^2 each. The total geometrical efficiency of the detector is ~2% of 4π, and intrinsic efficiency of detection of 2.5 MeV α-particles is close to 100%. Figure 4 shows counting characteristics of three different segments of the α-detector for α-particle from the reaction d+t→n+α. Counting rates of α-

particles do not depend on the threshold in a wide range from –20 mV to –100mV, which is an indication of a close to 100% efficiency and insensitivity to parasitic radiations (electrons, scattered deuterons, light, X-rays).

Stability of the detector to radiation damages was checked at a large neutron generator NG-400 at Khlopin Radium institute. During the experiment the detector was bombarded by α-particles and neutrons from d+t→n+α reaction, and the total number of incident particles corresponded to 5000 hours work of a portable neutron generator with intensity 108 n/s. Although irradiation of the detector resulted in the degradation of its spectroscopic properties, its ability to count incident α-particles with energies ~2 MeV did not suffer, as this is all that is needed for an NNA-based device.

2.2 Detectors of γ-rays

SENNA includes two detectors of γ-rays based on BGO ($Bi_4Ge_3O_{12}$) crystals with dimensions ∅63mm×63mm, and Hamamatsu R6233-01 photo multiplier. The choice of BGO was dictated by their high efficiency to γ-quanta and small dimensions, which allows one to minimize the dimensions and weight of the shielding, which protects crystals from direct flux of neutrons from the target of the neutron generator.

The energy resolution of detectors is 10% for 662 keV ^{137}Cs line, which is close to resolution of NaI-based detectors of the same efficiency. Time resolution of the detectors is about 1.8 ns for γ-quanta with energy 4.43 MeV (line from reactions on carbon).

The decay time of BGO is about 300 ns, which allows one to these crystals at counting rates up to several units to 10^5 s^{-1}. Stability of energy and time resolutions at such high counting rates is achieved by using real-time digital signal processing (see the next section).

Light output of BGO crystals depends rather steeply on temperature (more than 0.5% per degree centigrade at room temperature). This effect, however, plays insignificant role for SENNA, since typical measurement times with SENNA are of the order of one minute; this time is not enough for the temperature of the crystal to change noticeably. Crystals' temperature is monitored by the temperature gauge built into the detector.

2.3 Spectrometer and data acquisition system

Spectrometer and data acquisition system used in SENNA provides the following information about every detected γ-quantum:

- energy;
- time-of-flight relative to the α-particle associated with the neutron, which produced this γ-quantum;
- detector hit position by this α-particle.

Time-of-flight and α-particle position information are used to determine the location in space, from which the γ-quantum was emitted. Energy spectra of γ-rays are used to determine chemical composition of the inspected volume. According to the ideology of NNA, γ-quanta that are not correlated in time with any of the detected α-particles are rejected, since they are not connected with the reactions in the material of interest.

Spectrometer and DAQ receive on their inputs two streams of events. The first stream contains logical pulses "time" and "position" formed by the electronics of the associated α-particle detector (up to 10^7 events per second). The second stream is formed by ~1.5 ms-long pulses from two detectors of γ-rays (>10^5 events per second per detector).

The spectrometer and DAQ are modular. The stream of events from α-detector is analysed by the "alpha-module", which determines time of arrival of the "time" signal from the α-detector relative to the internal 100 MHz clock with accuracy 125 ps, and makes this information (and the α-particle position information) available to other modules via a dedicated bus clocked by the same 100 MHz. Signals from each of the γ-ray detectors go to the input of the corresponding "gamma-module", are digitised by ADCs working at the same 100 MHz frequency, and are then analysed by the programmable logic devices (PLD). PLD checks whether the bus contains information about an α-particle (time and position) in the required time interval, and if not – interrupts processing and rejects the γ-quantum. If such information is available, PLD forms properly digitised signal from the γ-ray detector, subtracts zero level, determines time of arrival of the pulse relative to the same 100 MHz clock, calculates time of flight of the γ-quantum relative to the α-particle, and integrates the pulse from the γ-detector in the selected interval. Additional digital signal processor (DSP) after PLD allows one to perform more complex pulse processing. The resulting information about energy, time-of-flight and position is stored in buffer memory for further transfer to the analysing computer.

Use of digital signal processing allows one to select from the incoming streams of α- and γ-events only those that are correlated in time. In typical measurements with SENNA the intensity of the incoming streams of signals are $(3\text{-}5)\times10^5\alpha^{-1}$ and $(3\text{-}5)\times10^5\gamma^{-1}$, and the counting rate of coinciding events that are selected for the subsequent analysis is about 1000 events per second. The achieved time resolution of about 2 ns for γ-rays with energies above 2 MeV corresponds to position sensitivity in-depth of the order of 10 cm, while position resolution in-plane, which is determined by segmentation of the α-detector, is ~7cm×7cm at 40 cm from the target of the neutron generator.

2.4 Data analysis

Data analysis in SENNA begins with applying energy and time calibrations. Parameters of the time calibration are determined during the initial tuning of the system separately for each of the nine segments of the α-detector. This calibration transforms the time-of-flight of the γ-quantum and the number of the hit segment of the α-particle detector into three coordinates (X,Y,Z) in centimetres, at which this γ-quantum was born.

Energy calibration of each of the γ-ray detectors is done automatically for each collected spectrum. This procedure uses the peaks that are always present in the full (non-coincident) γ-spectrum: e.g. 0.84 MeV iron peak and 4.43 MeV carbon peak. Iron and carbon are contained in the construction materials of SENNA, and the corresponding γ-rays are always present in enough quantities in spectra of secondary γ-rays that are collected without coincidences with any α-particles. Knowing the approximate position of these peaks in the spectrum, the calibration procedure determines their exact position by a conventional floating segment (sliding) method. Thus, the found calibration is always the best possible for the given spectrum, since it automatically compensates for all effects leading to line shift (temperature variations, counting rates, etc.) The only assumption is that the calibration is stable for the time of measurement (typically, about one minute), which is always fulfilled in practice.

Further data analysis consists in decomposition of energy spectra of γ-rays collected for every "voxel" of the inspected volume, into contributions from various chemical elements. Response functions of the device on different elements were calculated by MNCP code, with due accounting for energy resolution,

time of flight, detector geometry and other factors. An example of response functions to carbon, nitrogen and oxygen is shown on Figure 5. Calculated response functions coincide with the experimental ones, measured for pure carbon, water (hydrogen does not produce γ-rays in reactions with fast neutrons), and liquid nitrogen.

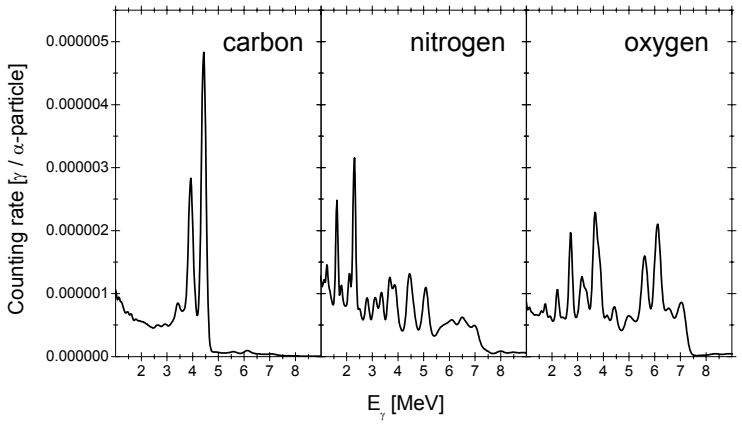

Figure 5. Calculated response functions of SENNA for 100g of carbon, nitrogen, and oxygen.

The spectral library of SENNA includes response functions to all chemical elements of the periodic table up to arsenic, except hydrogen and noble gases.

Use of NNA allows one to obtain multiple γ-ray spectra (one for each "voxel" of the sensitive volume – see Figure 1) in a single measurement. Since in real measurement the location of the hidden object is usually unknown, γ-ray spectra are built in coincidence with each of the nine segments of the α-detector for "voxels" overlapping along the in-depth coordinate. The size of such voxel in-depth is 10 cm (determined by time resolution of the system), and the size in-plane depend on the distance to the target of the neutron generator (7cm×7cm at distance 40 cm). For example, if the simultaneously inspected volume at Figure 1 is probed at depths from 1 cm to 50 cm, then $9 \times 50 = 450$ γ-ray spectra are simultaneously constructed. Decomposition of these spectra into response function is then done independently.

Decomposition of spectra into a large number of components (in SENNA response functions of 26 chemical elements are simultaneously used) is a non-trivial task, especially when spectra are collected with small statistics to reduce the inspection time. Use of standard decomposition methods like least squares fitting (LSF) leads to matrices with near-zero determinants, and therefore to very unstable results. The only option in LSF is to limit the number of components, or to try different sets of components with the hope of finding the best one for the given spectrum. While such "tricks" may work in laboratory conditions, when the experimenter has the full control over chemical composition of the inspected object, in real-life measurements such unjustified limitations on the number the components lead to inevitable and unpredictable errors.

SENNA uses another method of decomposition of experimental spectra into response function – partial least squares (PLS), which is a combination of LSF and principal component analysis (PCA). The specially developed version of PLS allows one to simultaneously include all the important chemical elements into the decomposition procedure, while keeping the procedure stable even at low statistics.

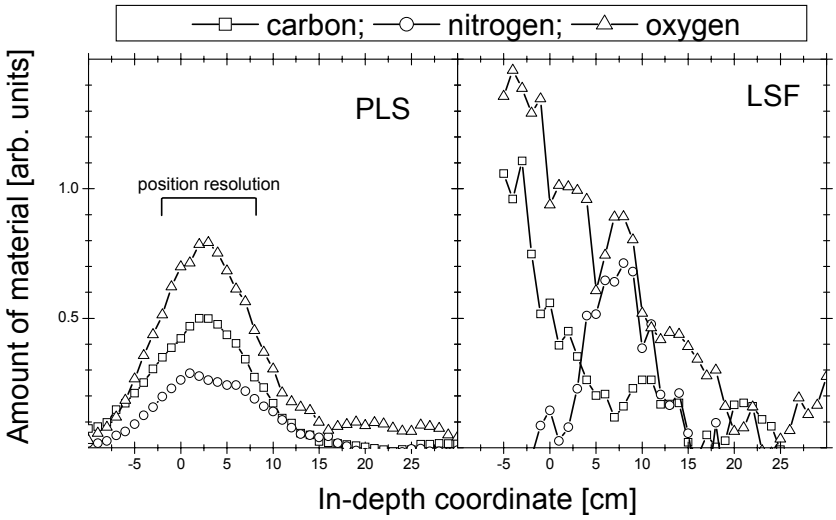

Figure 6. Comparison of concentrations of carbon, nitrogen and the oxygen, obtained from the same spectra (400g TNT imitator) by PLS (left) and LSF (right).

Figure 6 shows results of applying LSF and PLS with the same set of response functions to the same γ-ray spectra from 400g TNT in the same energy interval (1 MeV < E < 8 MeV). In case of PLS (left), the distribution of concentrations of carbon, nitrogen and oxygen in the sample are restored correctly, while in case of LSF (right) the obtained concentrations bear no resemblance whatsoever to the real ones, which is an expected outcome for LSF with so many components applied to low-statistics spectra.

2.5 Automatic decision-taking procedure

PLS provides reliable decomposition of energy spectra of γ-rays into contributions from different chemical elements, yielding relative concentrations (with error bars) for all elements in all voxels of the inspected volume. Now, this information, as well as other information about duration of measurement, intensity of the neutron generator, etc., should be used to make a decision about presence or absence of the substance of interest in the inspected volume, about its mass, exact location, and about the degree of reliability of these results.

At an early stage of SENNA's development the principal component analysis (PCA) [5] was used to determine the likelihood that the detected substance is in fact the chemical compound of interest (for example, an explosive). Later, however, it was found out that this method works well only in case of "pure" substances (e.g. pure TNT). Presence of impurities distorting the ratios of chemical elements in the object (for example when an explosive is in a suitcase containing also plastic, paper, etc.), may prevent PCA from correctly identifying the found substance.

At present the SENNA's automatic decision-making procedure is based on "fuzzy logic" (FL) method. This method [6] allows one to use many capabilities of neural networks to analyse heterogeneous (sometimes semi quantitative) information, while preserving the possibility of intuitive adjustment of the decision-making procedure and full control over its behaviour.

FL allows one to make precise (quantitative) conclusions on the basis of approximate ("fuzzy") information. For example, if one is looking for explosives, then in the simplest case one must require simultaneous presence of nitrogen, oxygen and carbon in the same voxel of the inspected volume. The

amount (or ratios) of these elements in the given voxel may not necessarily coincide which that in the "pure" substance (e.g. TNT), since it may depend on uncontrollable conditions: type of the explosive, absorption of γ-rays, presence of parasitic substance nearby, statistics, etc. Thus, setting exact threshold quantities for different elements may lead to mistakes. Fuzzy logic allows one to express quantitatively statements like "if there is a lot of carbon and a lot of oxygen and at least some nitrogen, then it is an explosive".

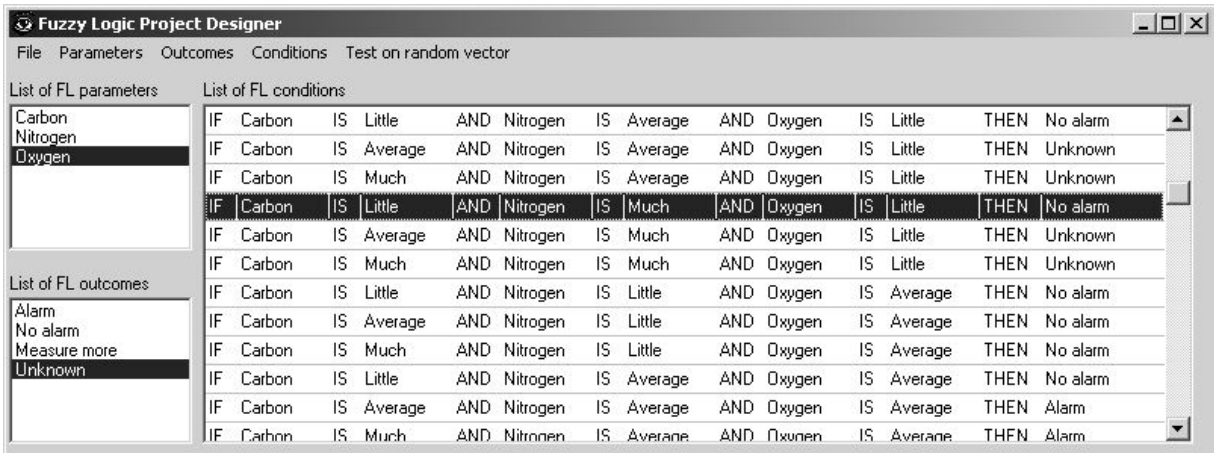

Figure 7. An example of the design window of the decision-making procedure for detection of nitrogen-containing explosives.

An example of setting a simple decision-making procedure is shown on Figure 7. In this example decision about presence of an explosive is based on simultaneous presence in any "voxel" of enough carbon, nitrogen and oxygen. The concept of "enough" for these elements is defined by using appropriate "membership functions", as prescribed by the FL algorithm.

The simple example shown above is appropriate only for detection of conventional military or industrial explosives, which contain carbon, nitrogen and oxygen. If one is looking also for non-nitrogen explosives, such as TATP, the decision-making procedure must also include analysis of the ratio between concentrations of carbon and oxygen.

More realistic FL-cased decision-making procedures, which have been developed for different detection scenarios with SENNA, also account for the measurement time, and one of the possible decisions becomes "continue the measurement". Thus, the system automatically determines the necessary measurement time, after which it is able come to a certain Yes/No decision.

Summarizing the above, SENNA performs data analysis in several stages:

- Constructing energy spectra of γ-quanta for all "voxels" of the sensitive area from the raw event-by-event data file. Since light output of BGO crystals depends rather steeply on temperature, automatic energy calibration is performed for each newly collected spectrum.
- Determining concentrations of key elements by partial least squares (PLS) and Principle Component Analysis (PCA) algorithm [5] – typically about 25 chemical elements are simultaneously used in the data fitting.
- Decision-making by "fuzzy logic".

Example of the SENNA program window indicating presence of threat objects in two red "voxels" in the inspected volume is shown at Figure 7.

Apart from showing the position of the threat object, the analysis software also provides the operator with the estimated mass of the threat object.

Figure 7. SENNA program window.

3.0 EXPERIMENTAL RESULTS

3.1 Suppression of the background due to NNA

Reduction of the background in NNA is achieved by choosing only those γ-quanta that are produced by fast neutrons in the given area of space ("voxel"). Most of the background in γ-ray spectra comes from reactions of neutrons with the substance that surrounds the object of interest. For example, when looking for small quantities of explosives in luggage the main contribution to spectra comes from γ-quanta produced by other objects inside the suitcase: clothing, books, household electronics, etc., not from the explosive itself.

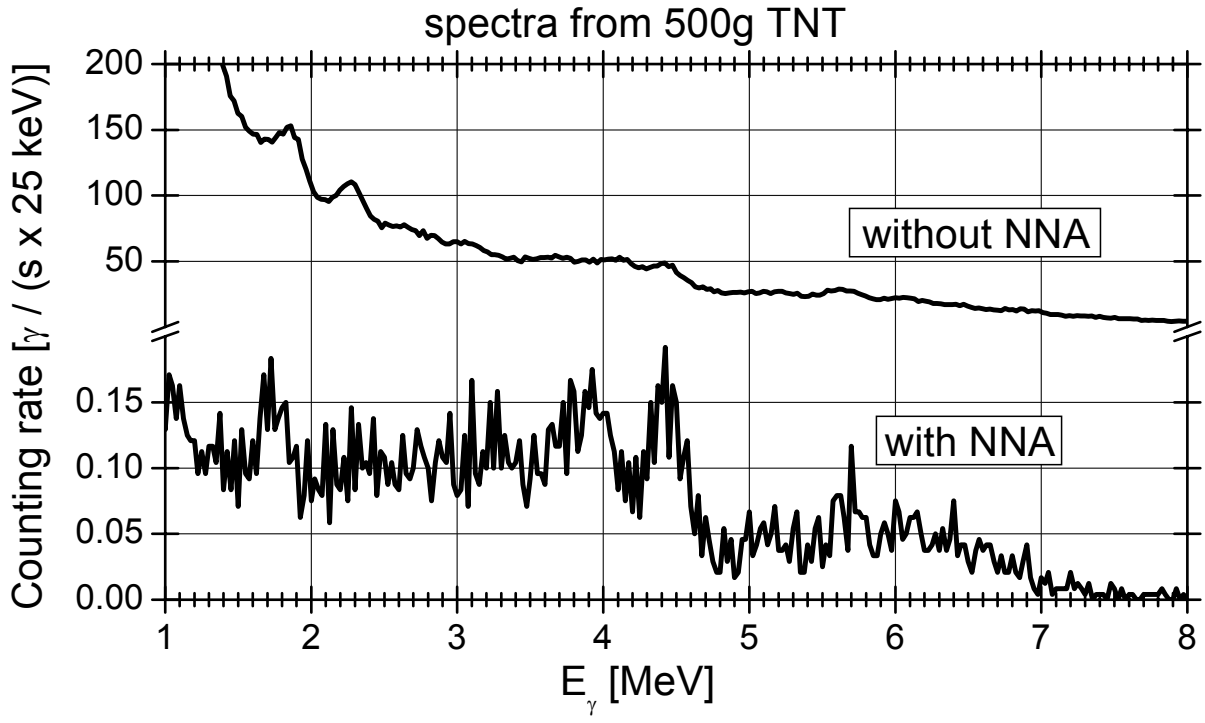

Figure 8. Comparison of γ-ray spectra obtained with and without NNA in measurement with 500g TNT imitator.

Figure 8 shows example of spectra obtained in the same measurement with 500g TNT imitator with and without applying the NNA procedure. The top spectrum was obtained without NNA, i.e. the data acquisition system accepted all incoming γ-quanta. The bottom spectrum was obtained with NNA: only those γ-quanta were accepted, which were born in the "voxel" containing the TNT imitator. One can see, that for example out of approximately 50 events per channel at 4430 keV (peak corresponding to reactions of fast neutrons with nuclei of carbon) only 0.15 are actually connected with reactions on TNT sample, while all other events come from surrounding walls, floor, elements of the device, etc. Obviously, any information about ratios of concentrations of chemical elements obtained from analysis of the spectrum obtained without NNA will have nothing to do with the TNT sample.

Thus, use of NNA allows one not only to reduce time of measurement, but also makes possible detection of small quantities of substance in presence of large masses of parasitic material.

3.2 Measurements with imitators of explosive substances (ES)

A series of measurements, simulating detection of explosives in various conditions, have been carried out with SENNA:

- Inspection of small isolated objects (e.g., explosives disguised as household goods, toys, etc.)
- Examination of luggage of air passengers and of suspicious unattended suitcases.
- Examination of cargo containers.

Figure 9 shows two spectra of γ-rays obtained in a single measurement in coincidence with two segments of the α-detector (#1 and #3, see Figure 1) for the same distances from the neutron generator target ("depth").

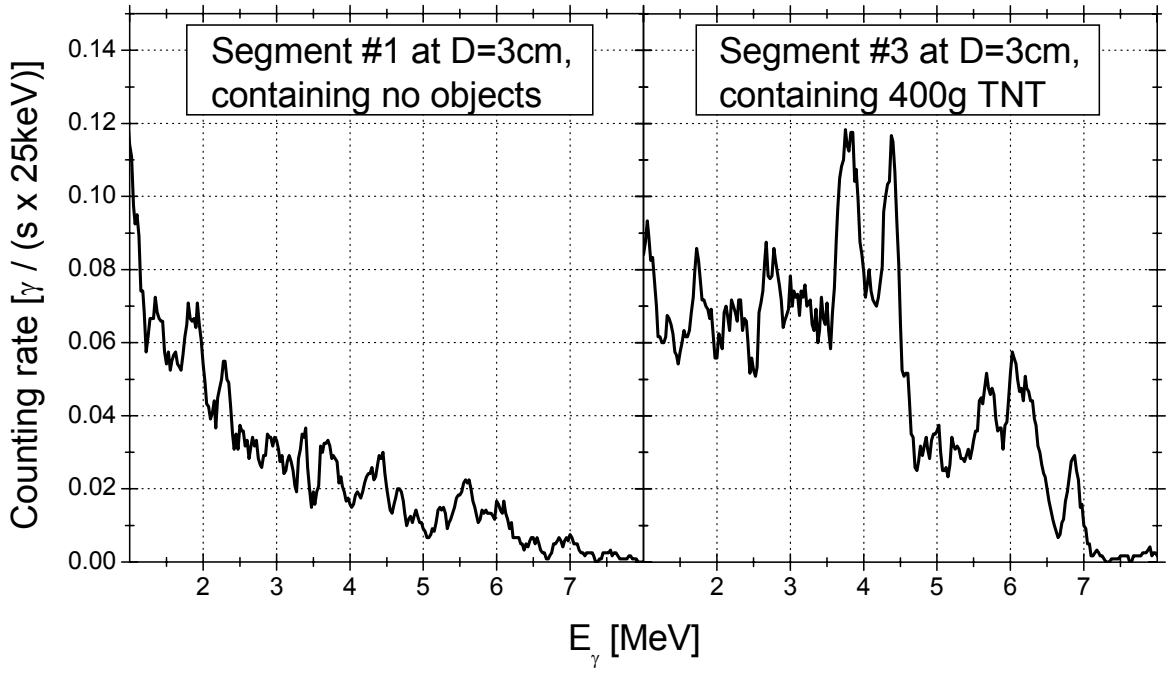

Figure 9. Comparison of energy spectra of γ-rays, measured in coincidence with two different segments of the α-detector for the same depth (D = 3 cm): segment #1 contained no objects, segment #3 contained 400g TNT.

The γ-ray spectrum obtained in coincidence with segment #1 of the α-detector can be used as the background in the analysis of the spectrum, obtained in coincidence with segment #3. The effect/background ratio in the energy range from 2 MeV to 7 MeV is about 5, compared to ~0.01 that are typically obtained by methods, which are not using NNA.

Figure 10 shows distribution of masses of carbon, oxygen and nitrogen along the in-depth coordinate for the above measurement with the 400g TNT imitator. Maximums at depth about 3 cm for segment #3 correspond to the location of the sample. Use of overlapping coordinate windows, that are sliding with 1 cm step along the in-depth coordinate, allow one to eliminate "bad" points originating from accidental behaviour of spectral statistics.

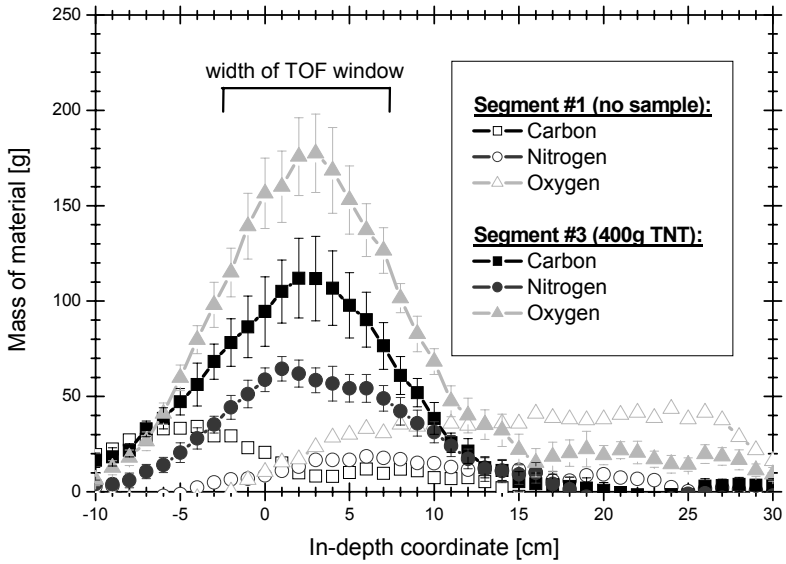

Figure 10. Distribution of carbon, nitrogen and oxygen along the in-depth coordinate, obtained from the analysis of the spectra measured in coincidence with segments #1 and #3 of the α-detector.

3.3 Measurements with real explosives (ES)

Experiments with different samples of TNT with masses ranging from 100g to few kilograms were carried out (Figures 11-13). Results of these and similar experiments were used to develop detection scenarios for inspection of different objects in various environmental conditions.

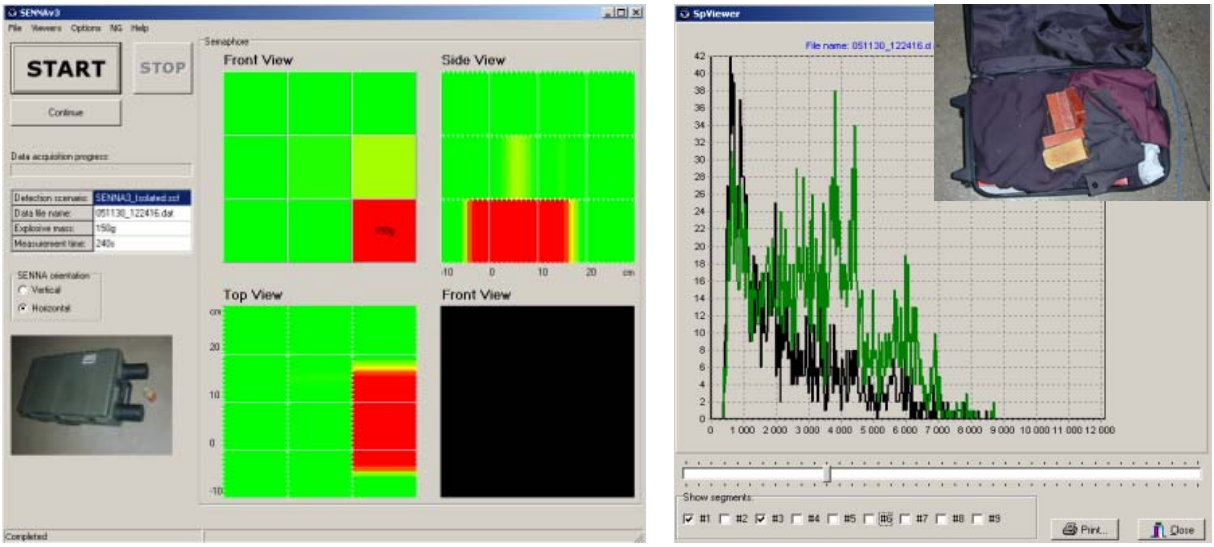

Figure 11. Example of measurements with TNT in a handbag filled with common goods (clothes, books, etc.) Left: 400g ES mostly found in segment #3 at depths from 0 cm to 10 cm. Suspicious area in segment #4. Right: Comparison of spectra from segment #3 and symmetric segment #1

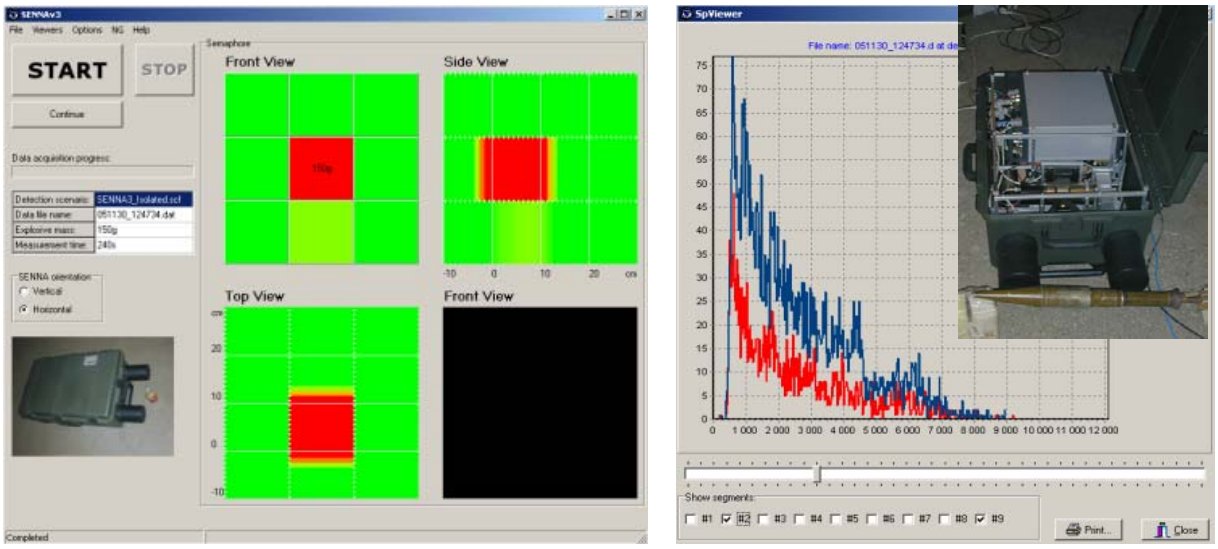

Figure 12. Example of measurements with antitank grenade (in segment #9). Left: 150g ES found in segment #9 at depths from 0 cm to 10 cm. Right: Comparison of spectra from segment #9 and segment #2 below it.

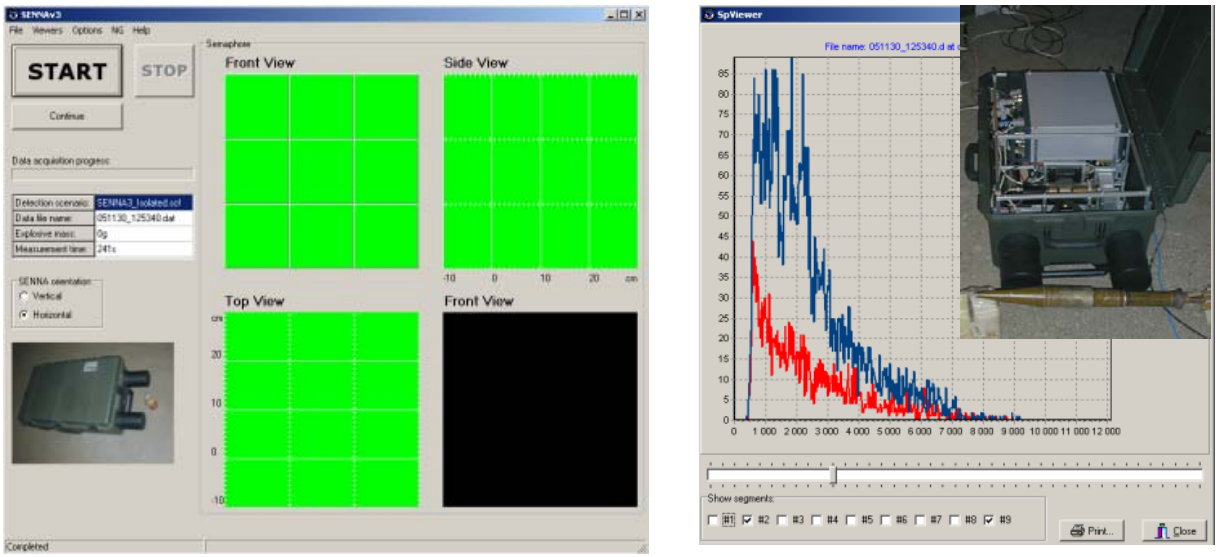

Figure 13. Example of measurements with antitank grenade with inert (non-explosive) filling (in segment #9) Left: No ES found. Right: Comparison of spectra from segment #9 and segment #2 below it.

3.4 Measurements with chemical weapons imitators (CW)

SENNA has been used to investigate the possibility of identification of shells, which can contain either an explosive charge, or a combination of an explosive charge and a toxic chemical. Several imitators were used, including those of 150 mm "DC" shell (diphenylcyanoarsine – vomiting gas), and 75 mm "explosive" shells. The measurement time was 30 seconds, and the total time for measurement + automatic data analysis was 1 minute.

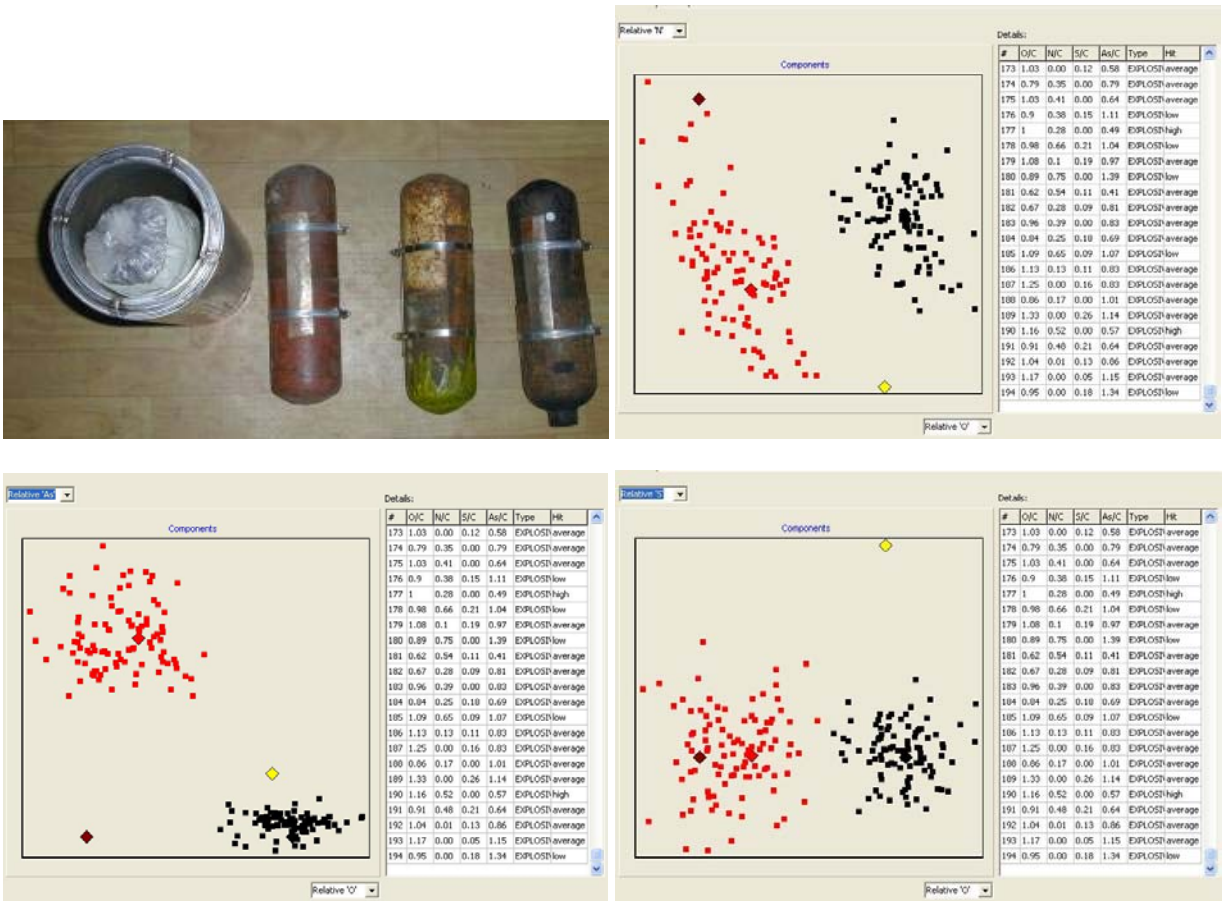

Figure 14. Results of measurement with imitators of chemical shells. The 2D plots are distribution of the experimental point in the coordinates O-As, O-N, and O-S.

The results of measurements are shown on Figure 14 as coloured points on oxygen-arsenic, oxygen-nitrogen, and oxygen-sulphur plots. One can see that the above imitators are well separated along some axes (oxygen, arsenic), while less reliably separated or even not separated at all along others (nitrogen, sulphur). However, when viewed in multi-dimensional space, the "clouds" do not intersect, so 100% correct identification was reached within 30 second-long measurements.

3.5 Measurements with IED explosives

SENNA can be used for identification of Improvised Explosive Devices (IED). In this case determination of the chemical composition of IED can be done quite easily, since the NNA technique is sensitive to a large variety of chemical elements, which can constitute IED. The main problem then becomes automatic analysis of these data in order to decide whether the found material is explosive or not. In other words, the system must determine the chemical formula of the found object from its measured physical characteristics, such as concentrations of different chemical elements. This problem can be solved by using an algorithm based on "fuzzy logic", which includes some *a priori* information about chemicals that can be used for terrorist purposes. Experimental and theoretical development of such "libraries" of spectra and chemicals is currently under way.

4.0 CONCLUSIONS

The device for detection of concealed explosives SENNA is capable of finding small amounts of explosives (starting with hundreds of grams) concealed among large amount of material in about a minute. Components of the device can be used to build specialized devices for specific applications (inspection of luggage, examination of suspicious objects, analysis of contents of cargo containers, etc.), as well as to create universal portable explosive detectors. Characteristics of the existing prototype:

Detection/Identification method	Nanosecond neutron analysis (NNA/APT)
Decision-making algorithm	automatic
Simultaneously inspected volume	~ 30×30×50 cm^3
Spatial resolution	7-10 cm in-plane, 10 cm in-depth
Total mass of the device	35 kg
Dimensions of the device	90×50×30 cm^3
Life time of the vacuum tube	>200,000 measurement cycles before changing (estimated)
Radiation safety	safe when switched-off; safe distance when switched on: 5 m
Power consumption	<100 W

5.0 ACKNOWLEDGEMENTS

This work was supported in part by NATO "Science for Peace" project # CP NR SFR 981003, and CRDF "Next Step to the Market" award No. RP2-564-ST-03. APSTEC gratefully acknowledges financial contribution by the Russian Foundation for Assistance to Small Innovative Enterprises (FASIE).

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